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PERFORMANCE EVALUATION OF CI ENGINE ON DIESEL-ETHANOL-BIODIESEL FUEL BLENDS

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Abstract: The studies were conducted to standardize the level of constituents to obtain stable diesel-ethanol-biodiesel microemulsions prepared using anhydrous ethanol (200° proof) and aqueous ethanol of 195°, 190°, 185°, 180° and 175° proof and soybean biodiesel under wide ambient temperature range. A total of twenty blends of ethanol-diesel-biodiesel were prepared and their temperature stability in the range of 0-45 ^{0}C was studied in an interval of 5^0 starting from 45^{0}C. Based on full range temperature stability, four microemulsions (v/v) 200^0[1:0.053:0.14], 200^0[1:0.0.053:0.26], 190^0[1:0.11:0.62], 180^0 [1:0.25:1.54], diesel: ethanol: biodiesel were selected to study engine performance. On the basis of experimental study it was concluded that 200^0[1:0.053:0.35] diesel: ethanol: biodiesel microemulsion replacing 28.75 % diesel can be used in CI engine without any need for engine modification.

Key words: *biodiesel, microemulsions, proof of ethanol, surfactant*

INTRODUCTION

The world is presently facing the twin crisis of fossil fuel depletion and environmental degradation. Indiscriminate extraction and lavish consumption of fossil fuels have led to reduction in underground-based oil resources. World oil production is currently at about 4000 MMT (*million metric ton*) and is expected to reach 5200 MMT by 2030. By 2030, India will need three to four times as much as energy as we currently

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use, if our economy is to grow at 8 to 9 % a year. By 2030, we may need from 350 MMT to 500 MMT of oil a year, depending on our growth rate and the policies we follow. Our domestic production of crude is expected to be around 35 MMT. India's import of 300 MMT to 450 MMT will constitute 6 to 9 % of global production, up from less than 3 % today [1]. This necessitates developing and commercializing fossil-fuel alternatives from bio-origin. The fuels of bio-origin can provide a feasible solution to this worldwide petroleum crisis**.** Among the various alternative fuel options, ethanol has been singled out to be the most promising and prospective solution to the energy crisis of India because of large cellulosic biomass and sugarcane availability for its production.

As CI engines play an important role in developing economics which often are dependent on agriculture, ethanol diesel blends become all the more relevant [5]. The efforts made by some of the leading institutions in the country have shown that there is an advantage of using ethanol-diesel blends leading to 10 % to 15 % increase in power due to improved air utilization, efficiency and lesser pollution in certain range. 41% reduction in particulate matter and 5% NOx emission with 15% ethanol–-diesel blends are reported [6]. Net savings of 20% CO_2 emissions (46.7MMTy^{-1}CO2 equivalent) was achieved in Brazil due to ethanol and bagasse substitution from fossil fuel [7].Therefore, blending of ethanol even in small quantity could give beneficial results. The major drawback in e-diesel is that ethanol is immiscible in diesel over a wide range of temperatures. The amount of diesel replacement in the form of blend is limited with the occurrence of phase separation (immiscibility of ethanol with diesel) in the blend**.** Commercially available ethanol of 180°–160° proofs (10–20% water content) cannot be blended directly in diesel due to their distinct phase separation from diesel. The engine adjusted to ignite such fuel will produce less power, if ethanol separates from diesel [8].To overcome the problem of phase separation while preparing the blended fuel by using lower proof of ethanol or higher amount of diesel substitution, micro emulsification is the best technique, as it increases water tolerance capacity. The amount of diesel substitution can be increased to a great extent by the preparation of alcohol–diesel microemulsion using biodiesel as blending agent [9]. In view of the above scope for use of alternate fuels, a study was planned to formulate different diesel:ethanol:biodiesel microemulsions and thereafter study the performance of CI engine on stable formulated fuels.

MATERIAL AND METHODS

Micromulsified fuels. The microemulsions of different ethanol proofs with diesel were prepared at room temperature (25^{0}C) by simple splash blending using biodiesel as blending agent and then were kept at a temperature of 45, 40, 35, 30, 35, 30, 25, 20, 15, 10, 5 and 0 ^{0}C for 8 h at each temperature. The microemulsions that were found stable in the entire temperature range were selected for study of engine performance (Table 1).

Experimental Set-up. The test engine set-up used for its performance evaluation on above mentioned stable fuels consisted of the following facilities:

- A Kirloskar make, 3.73 kW, constant speed engine.
- A SAJ-Froude make, EC–15 model eddy current dynamometer with electronic controller to load the engine

- A SAJ-Froude make, SFV–75 model electronic volumetric fuel consumption measuring unit.
- A Nucon make, model 4900 hydrocarbon analyzer.
- A Nucon make, model 500, nitric oxide analyzer.

A Nucon make, model 500, nitrogen dioxide analyzer

Table 1. Microemulsified fuels selected for engine performance evaluation

Diesel: Ethanol: Biodiesel Microemulsions	*Diesel replacement (%)*
200^0 [1:0.053:0.14]	*21.81*
190^0 [1:0.110:0.62]	*42.86*
180^0 [1:0.250:1.54]	*64.21*
200^0 [1:0.053:0.35]	*28.75*
Diesel: Ethanol: Biodiesel Microemulsions	*Diesel replacement (%)*
2000 [1:0.053:0.14]	*21.81*
1900 [1:0.110:0.62]	*42.86*
1800 [1:0.250:1.54]	*64.21*
2000 [1:0.053:0.35]	*28.75*

Test engine. A Kirloskar make AV1 model, constant speed, four stroke, single cylinder, direct injection compression ignition engine was selected for the study. The engine is commonly used in agricultural operations as well as a prime mover in electric generators for domestic purposes.

Engine Performance Test. The fuel consumption test of the engine was conducted in accordance with IS: 10000 [P: 8]: 1980 [7]. The fuel consumption test was carried out on fuel types shown in Table 1. The engine was run for at least three minutes on each of the load conditions and thereafter various measurements were made at respective loads. The performance of the engine on selected stable fuels was evaluated at the following load conditions:

- No load
- 20% of the rated load
- 40% of the rated load
- 60% of the rated load
- 80% of the rated load
- 100% of the rated load
- 110% of the rated load

The following parameters were measured during the fuel consumption test**:**

- Engine speed [min^{-1}]
- Brake power [kW]
- Fuel consumption [$\mathrm{l \cdot h}^{-1}$]
- *UBHC* emission [%]
- NO emission [ppm]
- NO_2 emission [ppm]

The brake specific fuel consumption, brake thermal efficiency, brake mean effective pressure and energy input of the engine was also calculated

The engine speed (min^{-1}) as displayed by the electronic controller unit of eddy current dynamometer was recorded during the course of experiment at different loading conditions of the engine.

The brake power developed by the engine was calculated using the following equation:

$$BP = \frac{NT}{C} \tag{1}$$

where:

BP [kW] - engine brake power,
T [Nm] - engine torque,
N [min^{-1}] - engine speed,
C [-] - dynamometer constant = 9549.305

The fuel consumption was measured with the help of a SAJ-Froude make, SFV-75 model electronic volumetric fuel consumption measuring unit. The fuel to the engine was allowed to pass through the 25 ml pipette. The time taken for the consumption of 25 ml fuel was noted by means of a timer provided with the unit. The brake specific fuel consumption was calculated by using the relationship as given below:

$$BSFC = \frac{V_{cc} \cdot \rho \cdot 3{,}6}{BP \cdot t} \tag{2}$$

where:

$BSFC$ [kg·kWh^{-1}] - brake specific fuel consumption,
V_{cc} [cm^3] - volume of fuel consumed = 25,
ρ [g·cm^{-3}] - density of fuel,
t [s] - time taken to consume 25 cm^3 of fuel.

The brake thermal efficiency of the engine at different operating conditions was determined using the equation as given below:

$$\eta_t = \frac{K_s}{HV \cdot BSFC \cdot 100} \tag{3}$$

where:

η_t [%] - brake thermal efficiency,
K_s [-] - unit's constant = 3600,
HV [kJ·kg^{-1}] - gross heat of combustion.

The brake mean effective pressure (BMEP) of the engine at different loads was calculated using the relationship given below:

$$BMEP = \frac{2 \cdot BP \cdot k_c}{L \cdot A \cdot N \cdot n} \tag{4}$$

where:

$BMEP$ [Pa] - brake mean effective pressure,
k_c [-] - constant = $60 \cdot 10^{12}$,
L [mm] - stroke length,
A [mm^2] - cross sectional area of piston,
n [-] - number of cylinders.

The energy input (Q) per hour to the engine at different brake load conditions was calculated using the following relation:

$$Q = CV \cdot \rho \cdot FC \tag{4}$$

where:
Q [$MJ \cdot h^{-1}$] - energy input,
CV [$MJ \cdot kg^{-1}$] - calorific value of fuel,
FC [$l \cdot h^{-1}$] - fuel consumption.

Unburnt hydrocarbon measurement. A Nucon make, model 4900 hydrocarbon analyser was used for the measurement of unburnt hydrocarbon in the exhaust gases. The analyser has an electrochemical sensor and indicated the percent unburnt hydrocarbon in the exhaust gas. The measurements were made at different load conditions for each of the selected fuel types.

Nitric oxide measurement. A Nucon make, nitric oxide analyser, model 500-NO was used for the measurement of nitric oxide in engine exhaust gases. An exhaust gas sample drawn through an air pump operating on 230V AC was fed to the analyser for the measurement of nitric oxide content in exhaust gases.

Nitrogen dioxide measurement. The nitrogen dioxide content in engine exhaust gases emanating from burning of different fuel sample was measured with the help of a Nucon make, series 500 analyser.

RESULTS AND DISCUSSION

All the selected microemusions were studied for engine performance with diesel as baseline fuel to compare the results. The main results obtained are mentioned below.

Engine Parameters

Brake mean effective pressure of the engine at no load, 20, 40, 60, 80, 100 and 110% brake load on selected fuel types is shown in Tab. 2**.** It is observed from the data that there is a linear relation between brake mean effective pressure and brake load on various fuel types

Brake power developed by the engine on selected fuel types at no load, 20, 40, 60, 80, 100 and 110% brake loads i.e. at corresponding brake mean effective pressures and at corresponding engine speeds is shown in Tab. 2**.**

Table 2. Brake mean effective pressures of selected fuel types at different load conditions

Brake load (%)	*Brake mean effective pressure (bar)*	*diesel: ethanol: biodiesel microemulsions*							
		200^0[1:0.053:0.14]		*190^0[1:0.11:0.62]*		*180^0[1:0.25:1.54]*		*200^0[1:0.053:0.35]*	
		Engine speed (min^{-1})	*Brake power (kW)*	*Engine speed (min^{-1})*	*Brake power (kW)*	*Engine speed (min^{-1})*	*Brake power (kW)*	*Engine speed (min^{-1})*	*Brake power (kW)*
No L	*-*	*1566*	*0.00*	*1530*	*0.00*	*1544*	*0.00*	*1571*	*0.00*
20	*1.1*	*1530*	*0.77*	*1505*	*0.76*	*1522*	*0.77*	*1545*	*0.78*
40	*2.2*	*1527*	*1.52*	*1496*	*1.49*	*1507*	*1.50*	*1530*	*1.52*
60	*3.25*	*1521*	*2.28*	*1488*	*2.23*	*1495*	*2.24*	*1521*	*2.28*
80	*4.3*	*1519*	*3.02*	*1481*	*2.95*	*1487*	*2.96*	*1517*	*3.02*
100	*5.4*	*1507*	*3.74*	*1478*	*3.67*	*1480*	*3.67*	*1512*	*3.75*
110	*5.9*	*1477*	*4.04*	*1460*	*3.99*	*1458*	*3.98*	*1475*	*4.03*

It is evident from the table that engine developed marginally less brake power on the microemulsions compared to diesel at lighter load conditions. For the higher load conditions i.e. at 100 and 110% load, the brake power on microemulsions was marginally higher than the diesel. This result is consistent with the finding of Meiring *et,al.* [8] which states that the power reduction in lighter load region occurs due to reduced heat content of microemulsions and increase in ignition delay with alcohol when light loads are encountered.

Based on results on brake power developed by the engine on diesel and different microemulsions, it can be said that the microemulsions tested had similar power producing capabilities as diesel, though the amount of diesel replacement by microemulsions varied from 21.81 to 64.21%.

Fuel consumption. Tab. 3a shows the observed fuel consumption ($l \cdot h^{-1}$) of the engine at different brake meaneffective pressures (brake loads) on diesel and four selected microemulsified fuels. The relationship between the fuel consumption of the engine and brake mean effective pressure on different fuel types is presented in Fig. 1. It is evident from the figure that the fuel consumption of the engine gradually increased with increase in brake load and was found maximum at 110% brake load on all fuel types.

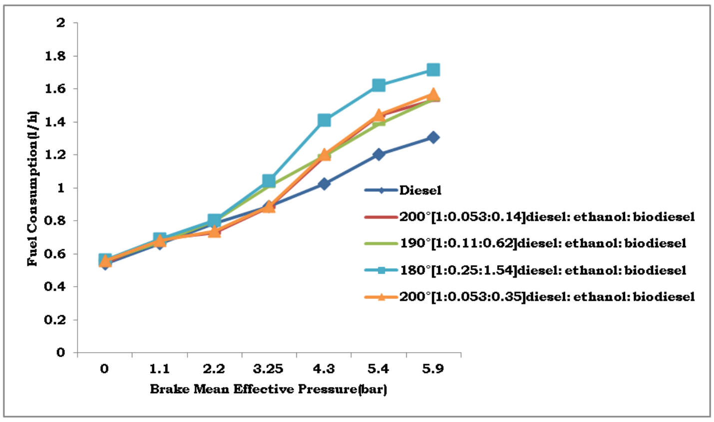

Figure 1. Fuel consumption at different brake mean effective pressures on selected fuel types

It is also evident from the figure that the fuel consumption of the engine on diesel was lowest at all the brake mean effective pressure conditions compared to the four microemulsions tested. This may be due to reason that the calorific values of tested microemulsions were 4 to 12% less than that of diesel.

Brake specific fuel consumption of the engine on diesel at rated load (engine developing *BMEP* of 5.4 bar was found 0.270 $kg \cdot kWh^{-1}$. Brake specific fuel consumption increased with the increased ethanol substitution and same has been reported by *Chaplin and Janius* [9].

The data from Tab. 3b also shows that the drop in the brake specific fuel consumption of the engine was at a higher rate upto 80% brake load (i.e. up to *BMEP* of 4.3 bar). Less change in the *BSFC* of the engine was observed between 80% and 110% brake loads. This is due to the reason that increase in brake power of the engine from

80% to 110% brake load was less as compared to increase in brake power between no load and 80% brake load. It is also evident from the figure that the *BSFC* of the engine at higher brake mean effective pressures was comparably higher on 180^0[1:0.25:1.54] diesel: ethanol: biodiesel compared to other microemulsion fuels.

Table 3. Engine performance paramaters on diesel and selected fuel types

Brake Load(%)	No Load	20	40	60	80	100	110
BMEP (bar)	-	1.1	2.2	3.25	4.3	5.4	5.9
a) Fuel consumption ($l\cdot h^{-1}$)							
Diesel	0.541	0.662	0.783	0.887	1.026	1.205	1.309
200^0[1:0.053:0.14] *	0.547	0.693	0.729	0.885	1.191	1.439	1.533
190^0[1:0.11:0.62] *	0.561	0.67	0.801	1.012	1.193	1.39	1.54
180^0[1:0.25:1.54] *	0.563	0.692	0.804	1.045	1.41	1.622	1.715
200^0[1:0.053:0.35] *	0.560	0.680	0.739	0.888	1.202	1.442	1.571
b) Brake specific fuel consumption ($kg\cdot kWh^{-1}$)							
Diesel	-	0.705	0.428	0.324	0.285	0.27	0.272
200^0[1:0.053:0.14] *	-	0.751	0.4	0.324	0.329	0.321	0.317
190^0[1:0.11:0.62] *	-	0.742	0.452	0.382	0.34	0.319	0.325
180^0[1:0.25:1.54] *	-	0.764	0.456	0.397	0.405	0.376	0.366
200^0[1:0.053:0.35] *	-	0.732	0.408	0.327	0.334	0.323	0.327
c) Brake thermal efficiency (%)							
Diesel	-	10.21	16.83	22.18	25.26	26.69	26.49
2000[1:0.053:0.14] *	-	10.13	19.01	23.49	23.61	23.7	23.63
1900[1:0.11:0.62] *	-	10.29	16.87	19.98	22.42	23.94	23.5
180^0[1:0.25:1.54] *	-	10.11	16.95	19.47	19.52	20.55	20.08
200^0[1:0.053:0.35] *	-	10.22	18.33	22.88	22.94	23.17	22.86
d) Energy input ($MJ\cdot h^{-1}$)							
Diesel	22.47	27.50	32.52	36.84	42.61	50.05	54.37
200^0[1:0.053:0.14] *	21.6	27.36	28.78	34.94	47.02	56.82	60.53
190^0[1:0.11:0.62] *	22.27	26.6	31.8	40.17	47.36	55.18	61.14
180^0[1:0.25:1.54] *	22.32	27.43	31.87	41.42	55.89	64.29	67.98
200^0[1:0.053:0.35] *	22.62	27.47	29.86	35.88	48.56	58.26	63.47

* *diesel : ethanol : biodiesel (V/V) microemulsions;*
ppm=parts per million;
BMEP= brake mean effective pressure

Brake thermal efficiency. It was observed that on an average, brake thermal efficiency on aqueous microemulsions was higher than that on diesel. This may be because of high heat of vaporization of alcohol which results into excessive cylinder cooling and therefore increased brake thermal efficiency at high loads.

Fuel energy input to the engine increased with increase in brake mean effective pressure and was observed highest at 110% brake load (i.e. *BMEP* of 5.9 bar) on all fuel types tested. The result of input fuel energy present in Tab. 3d shows that the maximum energy input at rated load was 64.29 $MJ\cdot h^{-1}$ on 1800[1:0.25:1.54] diesel : ethanol : biodiesel microemulsion. This may be because of high fuel consumption of this microemulsified fuel.

Exhaust emissions of the engine

Unburnt hydrocarbons. It is observed from the Tab. 4a that at lower brake mean effective pressures the microemulsions showed much higher *UBHC* emission as compared to that of diesel. The result is in accordance with the previous study [10] which reported increased *HC* emission for ethanol-diesel emulsions at part loads..The higher level ethanol blends generate greater *UBHC* emissions, and those with higher biodiesel level generate less *UBHC*. Due to its reduced cetane number ethanol will ignite later and will not burn completely, increasing in this way the unburned *HC* level from the exhaust gases [11]. It was also observed that the emission of *UBHC* was less on aqueous microemulsions as compared to anhydrous microemulsion at higher loads. The water content in aqueous microemulsions is responsible for reduced *UBHC* emission [12].

Table 4. Exhaust emissions of the engine on diesel and selected fuel types

Brake Load(%)	*No Load*	*20*	*40*	*60*	*80*	*100*	*110*
BMEP(bar)	*-*	*1.1*	*2.2*	*3.25*	*4.3*	*5.4*	*5.9*
a) Unburnt Hydrocarbons (%)							
Diesel	*0.04*	*0.03*	*0.03*	*0.01*	*0.04*	*0.12*	*0.21*
200^0*[1:0.053:0.14]*	*0.04*	*0.03*	*0.07*	*0.11*	*0.13*	*0.12*	*0.16*
190^0*[1:0.11:0.62]*	*0.06*	*0.06*	*0.1*	*0.09*	*0.08*	*0.11*	*0.2*
180^0*[1:0.25:1.54]*	*0.03*	*0.07*	*0.07*	*0.04*	*0.08*	*0.09*	*0.17*
200^0*[1:0.053:0.35]*	*0.04*	*0.02*	*0.05*	*0.07*	*0.11*	*0.12*	*0.2*
b) NO_2*(ppm)*							
Diesel	*23.4*	*47.8*	*86.8*	*92.4*	*61.3*	*53*	*40.2*
200^0*[1:0.053:0.14]*	*25.2*	*49.3*	*86.8*	*92.4*	*67.3*	*67.2*	*50.1*
190^0*[1:0.11:0.62]*	*22.2*	*44.2*	*90.6*	*115.3*	*115.01*	*84.3*	*77.2*
180^0*[1:0.25:1.54]*	*42.6*	*61.3*	*125.4*	*190.6*	*188.3*	*100.2*	*74.3*
200^0*[1:0.053:0.35]*	*19.2*	*32.2*	*77.6*	*105.3*	*102.46*	*99.3*	*99*
c) NO (ppm)							
Diesel	*70.7*	*132.3*	*216.8*	*307.3*	*170*	*154.2*	*160*
200^0*[1:0.053:0.14]*	*112.3*	*146.8*	*297.3*	*424.5*	*194.2*	*200.5*	*330.4*
190^0*[1:0.11:0.62]*	*90.2*	*210.3*	*330.4*	*520.6*	*627.3*	*260.2*	*360.3*
180^0*[1:0.25:1.54]*	*100.36*	*300*	*410.2*	*400.2*	*460.12*	*690.3*	*580*
200^0*[1:0.053:0.35]*	*70.2*	*140.3*	*247.4*	*497.3*	*204*	*190*	*238.33*

Nitrogen dioxide. It is evident from the data presented in Tab. 4b that NO_2 emission from the engine on all microemulsions was found lower than diesel fuel under no load to 60% load (i.e. upto 3.2 bar *BMEP*). NO_2 emission increased sharply beyond 60% load for all microemulsions. NO_2 emission was found more for diesel : ethanol : biodiesel emulsions as compared to diesel. This may be probably because of the higher oxygen content and better combustion of biodiesel fuels, and as a consequence, the combustion temperature increases, as reported by researchers[13] [14].

Nitric oxide. The emission of NO from the engine on diesel varied in the range 70.7 to 407.3 ppm at various brake mean effective pressures while for all microemulified fuels it was found higher than diesel. Presence of oxygen molecule in ethanol causes an increase in combustion temperature thereby resulting in increased NO_x emissions [15] [16]. It was also observed that microemulsions having lower proof of ethanol produced less NO emissions. This is because of the reason that water decreases the flame temperature and, consequently, decreases the formation of thermal NOx**.**

CONCLUSIONS

- From the experimental findings it can be concluded that microemuslions tested had similar power producing capabilities as diesel, though the amount of diesel replacement by microemulsions varied from 5.94 to 64.21%.
- Based upon the engine performance test results it is imperative that 200^0[1:0.053:0.35] diesel : ethanol : biodiesel microemulsion replacing 28.75 % diesel may be recommended for use in CI engine without any engine modification.

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OCENA PERFORMANSI DIZEL MOTORA PRI UPOTREBI DIZEL-ETANOL-BIODIZEL MEŠAVINE GORIVA

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Sažetak: Istraživanja su sprovedena da bi se standardizovao nivo sastojaka u cilju dobijanja stabilnih mikroemulzija dizel-etanol-biodizel, pripremljenih upotrebom dehidriranog etanola (čistoća 200°) i hidriranog etanola čistoće 195°, 190°, 185°, 180° i 175° i biodizela od soje pri širokom opsegu ambijentalnih temperatura. Ukupno dvadeset mešavina dizel-etanol-biodizel je pripremljeno i ispitivana je njihova temperaturska stabilnost u opsegu od 0-45°C, u intervalima od po 5°, počevši od 45°C. Na osnovu punog opsega temperaturske stabilnosti izabrane su četiri mikroemulzije dizel-etanol-biodizel (v/v): 200^0[1:0.053:0.14], 200^0[1:0.0.053:0.26], 190^0[1:0.11:0.62], 180^0 [1:0.25:1.54], za ispitivanje performansi motora. Na osnovu eksperimentalnog ispitivanja zaključeno je da se mikroemulzija dizel-etanol-biodizel 200^0[1:0.053:0.35] može upotrebiti kao zamena za 28.75% dizel goriva u dizel motoru bez ikakvih modifikacija na motoru.

Ključne reči: *biodizel, mikroemulzije, čistoća etanola, surfaktant*

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